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U. Lüdtke

Numerical simulation of free surfaces of liquid metal under the influence of Lorentz-forces

Introduction

In the frame of the research group „Magnetofluiddynamics“ of the Technical University of Ilmenau a simulation tool for modelling flow problems under the influence of Lorentz-forces was developed. It was carried out as additional task of the research group „Magnetofluiddynamics“ outside of their DFG-project [1]. The goal of this study is to enable the simulation of coupled electromagnetic and hydrodynamic problems including free surfaces. For the coupled field problem the self-developed program PROMETHEUS for solving Maxwell-equations and the commercial program FLUENT for solving Navier-Stokes equations is used. The shape of the free surface and information about its stability are the subjects of interest. In the projects A-3 and A-4 of the research group „Magnetofluiddynamics“ the validation of the simulation tool with experimental and analytical methods was carried out. The presented simulation tool allows the calculation of stable solutions for existing coupled hydrodynamic and magnetic flow problems, and obtains stationary free surfaces in good agreement with qualitative experimental results [2]. The presented coupling of FLUENT and PROMETHEUS has the following additional advantages: The commercial program FLUENT used for calculations of fluid flow with free surfaces represents a validated program incorporating many flow models and expert knowledge. The Volume of Fluid (VoF) method is used for the calculation of the free surfaces. The fixed grid of this method is very convenient for the coupling of the two programs. To show the possible field of application of this simulation tool two examples are presented.

Coupling of PROMETHEUS and FLUENT

In a previous version PROMETHEUS and FLUENT worked on different computer systems and the necessary data were transferred via web. Therefore a very complicated program control was required [2]. In the recent version the self-developed finite element program PROMETHEUS is fully implemented in the user-defined-functions of FLUENT. This is very efficient because the data transfer between PROMETHEUS and FLUENT only happens in the memory of the computer and an external control program for the coupling isn't necessary. The reason for doing this only now in a second version is the source code of PROMETHEUS, which had to be translated from the programming language Delphi to C++.

The grid is created by the PROMETHEUS-tools and FLUENT imports the grid from PROMETHEUS. Before the start of the simulation tool a so-called "case file" must be created for the use of FLUENT. Material properties, boundary conditions, models and other necessary parameters are defined. PROMETHEUS gets the information about the free surface from FLUENT by the so-called volume fraction. The volume fraction is the percentage of galinstan of each element. The volume fraction ranges between 0 and 1. A value 1 indicates that the element is entirely consisting of galinstan while a value of 0 indicates an exclusively air-filled element. The volume fraction is used to weight the electric conductivity in the galinstan/air region. With this method the distribution of the electric current density is obtained. Some elements on the surface of the drop represent a lower current density than elements below the surface. This is based on the fact that most of the surface elements are not entirely consisting of galinstan, and therefore does not represent a disagreement between experimental and model results.

The hydro-dynamical flow of the metal drop is calculated depending on time. After each time step the change of the volume fraction is checked. If it exceeds a limit then the Lorentz-force are calculated by PROMETHEUS again. The calculation is carried out with sinusoidal field data implying the use of complex variable domains. It is possible to calculate the heat sources too therefore it is also possible to calculate the fluid flow including the temperature field. The simulation tool is able to calculate problems both in two-dimensional Cartesian or Cylindrical coordinates.

A falling liquid metal drop

Fig. 1 to Fig. 3 show the results of a simulation of a galinstan drop falling through an inductor with an alternating current of 2000A and a frequency of 10000Hz. Fig. 1 shows the magnetic flux lines when the drop is in the middle of the coil. No strong deformation of the flux lines is observable.

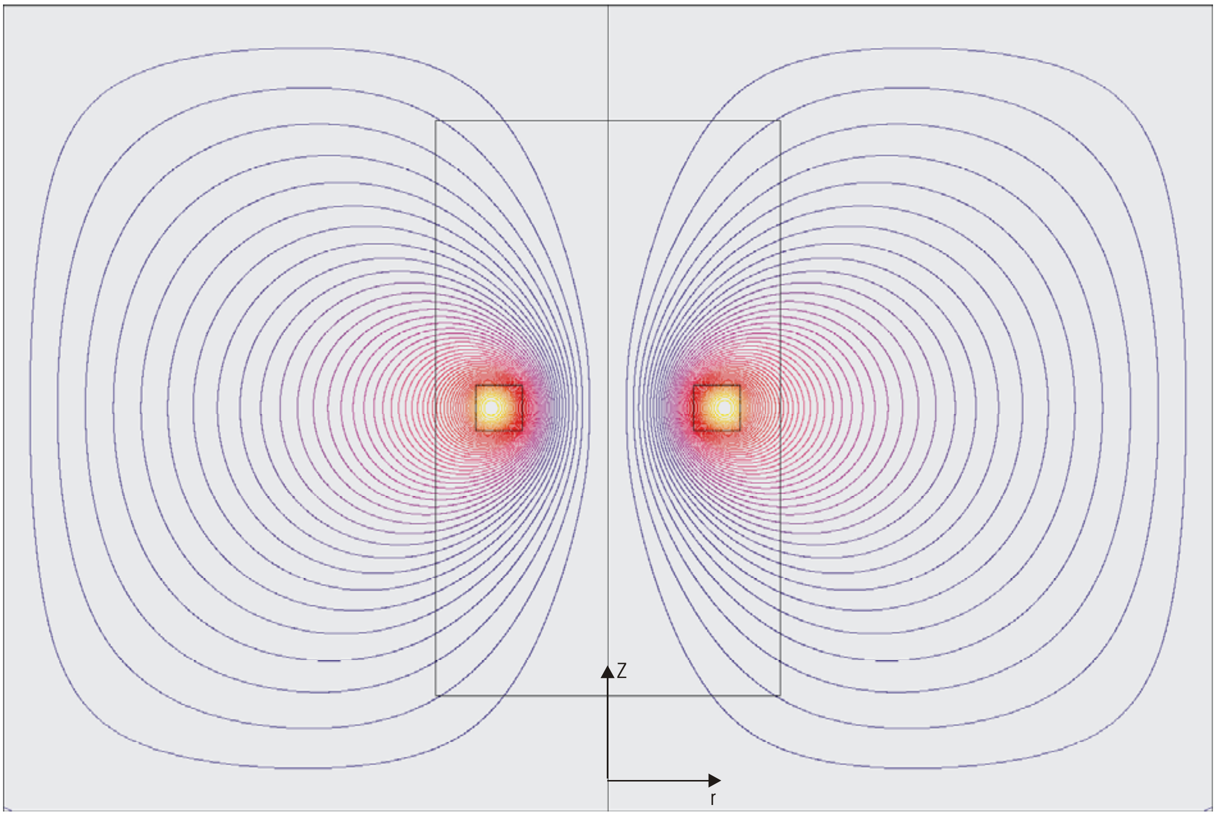

Fig. 1. Magnetic flux lines, calculated by PROMETHEUS – time = 0.11s (see Fig. 3)

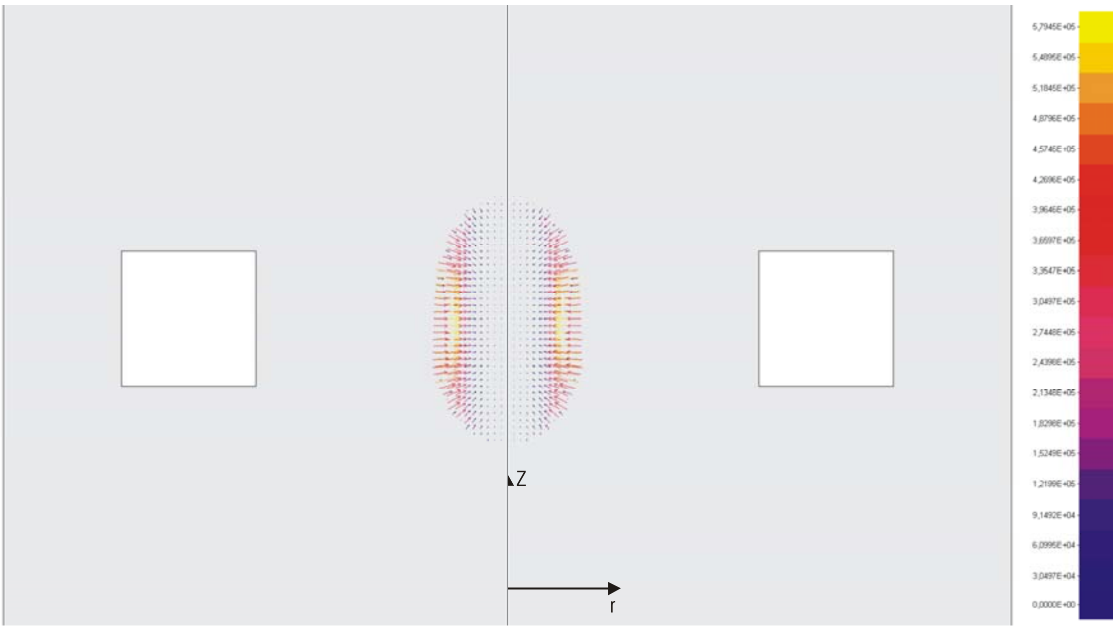

Fig. 2. Lorentz-forces in the liquid metal drop – time = 0.11s (see Fig. 3)

No direct view to the geometry of the drop is possible by using PROMETHEUS. At the same point in time Fig. 2 shows the Lorentz-force trying to pinch the liquid metal drop. Fig. 3 shows the drop at various points in time. Caused by the Lorentz-force the deformation of the drop is clearly to observe. For a better analysis a video-animation of the falling drop can be used. Next steps could be parameter studies for the current or frequency.

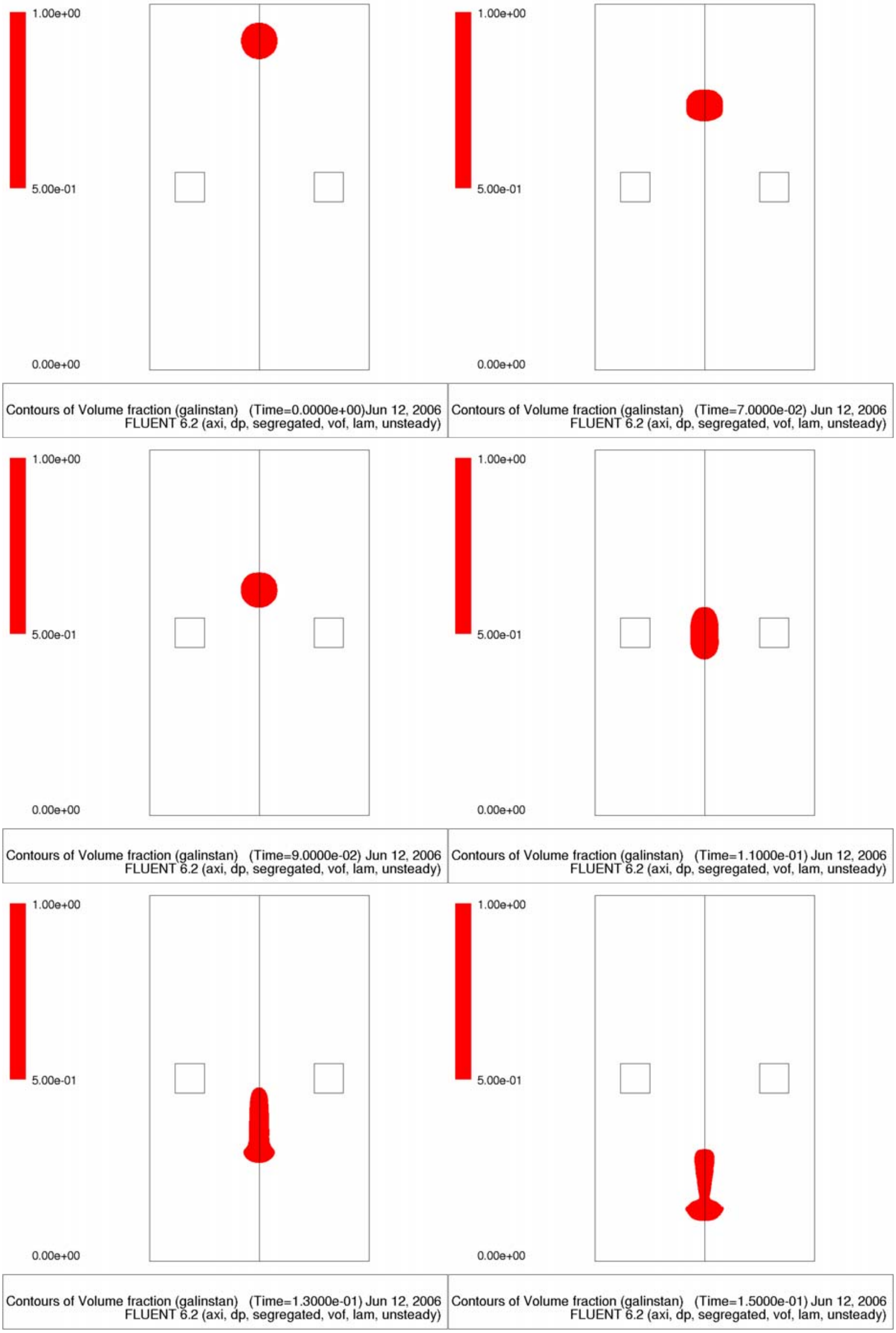

Fig. 3. The liquid metal drop at various points in time

A levitating liquid metal drop

Fig. 4 to Fig. 6 show the results of a simulation of a liquid metal drop with a dynamic viscosity of 1 Pas levitating in a pair of coils with an alternating current of 2000A and a frequency of 10000Hz. Fig. 4 shows the magnetic flux lines for this steady state. No strong deformation of the flux lines is observable.

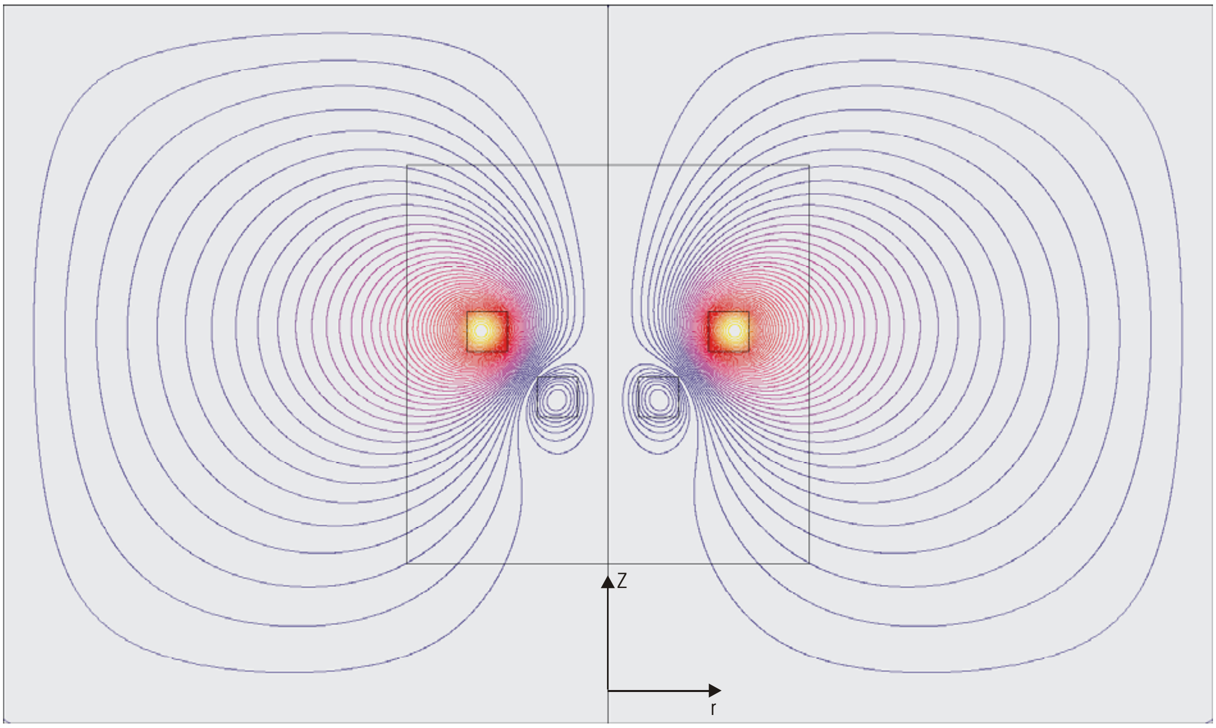

Fig. 4. Magnetic flux lines, calculated by PROMETHEUS (see Fig. 6)

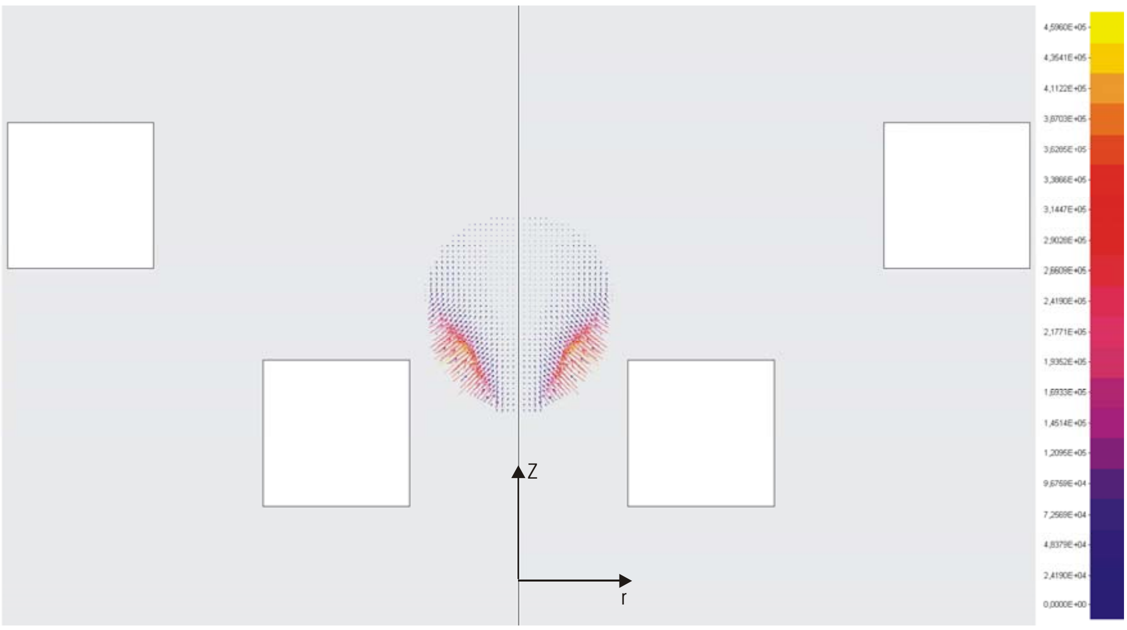

Fig. 5. Lorentz-forces in the liquid metal drop (see Fig. 6)

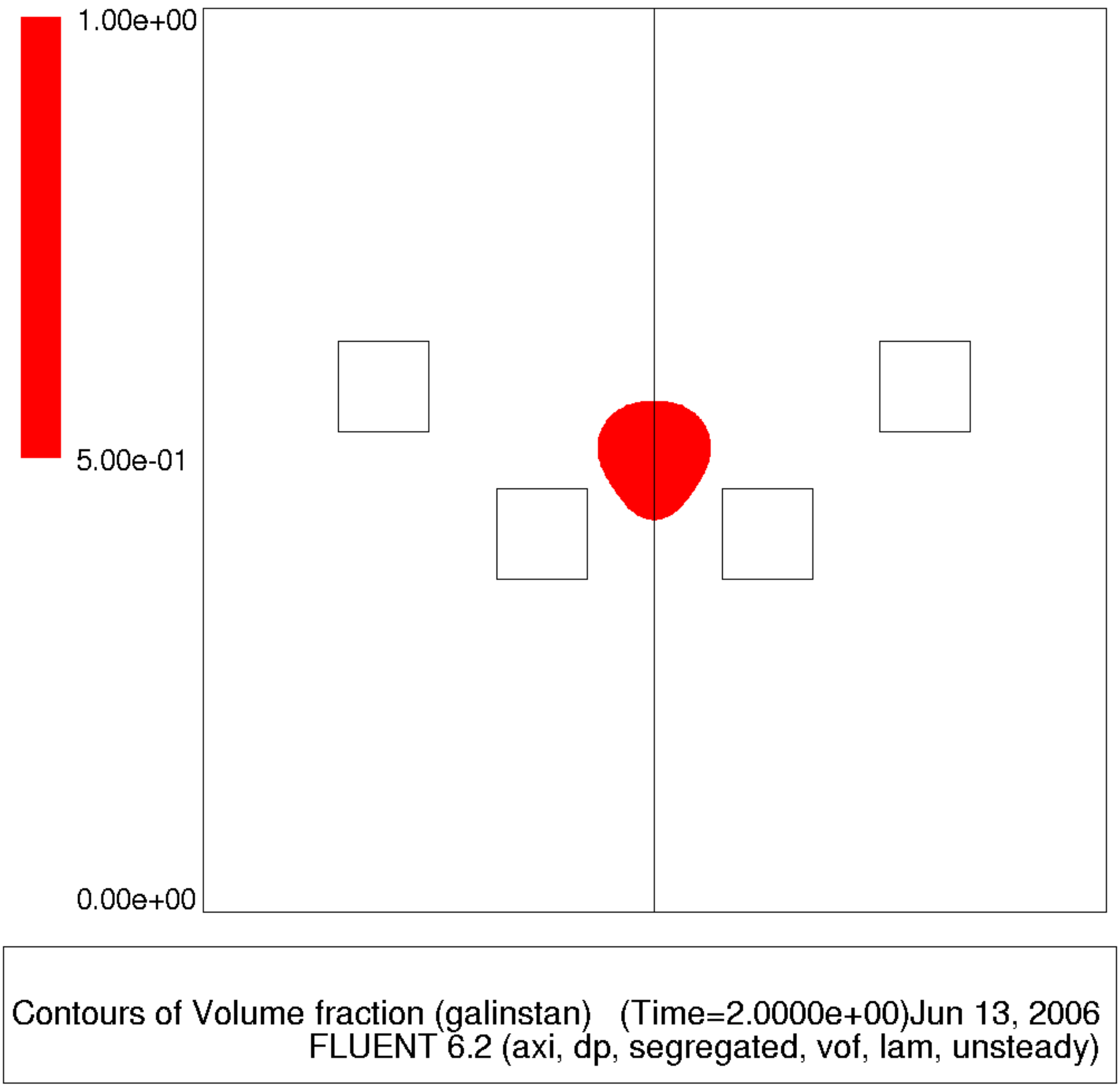

Fig. 6. The levitating liquid metal drop - steady state

Fig. 5 shows the liquid metal drop for the steady state. The Lorentz-force causes the deformation of the drop shown in Fig. 6. For a better analysis a video-animation of the falling drop can be watched. Next steps could be parameter studies for the current or frequency. Increasing the surface tension and the viscosity means to approach to a solid sphere.

Conclusions

The presented example demonstrates the acceptability of the simulation tool for the calculation of moving liquid metal drops under the influence of Lorentz-forces. The axis symmetric model doesn't allow any conclusion about the stability or instability in azimuthal direction. The present goal of the research group "Magnetofluiddynamics" is the extension of the simulation tool to three-dimensional problems. The implementation of the PROMETHEUS-code into FLUENT and the optimisation of the coupling process are requirements for the extension to three-dimensional problems.

References:

[1] Forschergruppe Magnetofluiddynamics der TU-Ilmenau: http://www.tu-ilmenau.de/mfd

[2] U. Lüdtke, Ch. Karcher, Numerical simulation of a liquid metal drop under the influence of Lorentz-forces, International Scientific Colloquium, Modelling for Electromagnetic Processing, Hannover, March 24-26, 2003

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